NASA TECHNICAL NOTE

NASA TN D-5848

c. 1

NASA TN D-5848

LASER BREAKDOWN OF COPPER VAPOR

by Victor E. Scherrer

Electronics Research Center
Cambridge, Mass. 02139

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1970

1. Report No. NASA TN D-5848	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Laser Breakdown of Copper Vapor		5. Report Date June 1970
		6. Performing Organization Code
7. Author(s) Victor E. Scherrer		8. Performing Organization Report No. C-123
9. Performing Organization Name and Address Electronics Research Center Cambridge, Mass.		10. Work Unit No. 129-02-20-03-25
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration		13. Type of Report and Period Covered Technical Note
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A novel technique for generating a plasma by combined deposition of energy from an electrical discharge and focused laser light is described. Initial heating was by electrical discharge. This was followed by optical heating, using a Q-switched ruby laser. Measurements were made of the optical power per unit area, required to produce breakdown in the expanding copper vapor. It was found that breakdown was produced for laser power per unit area of 10^9 to 10^{10} watts/cm^2.

17. Key Words	18. Distribution Statement
. Plasmas . Lasers . Optical Heat	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	8	$3.00

LASER BREAKDOWN OF COPPER VAPOR

By Victor E. Scherrer
Electronics Research Center

SUMMARY

The laser breakdown of copper vapor has been investigated as a contributing mechanism for increasing the energy density of exploding wires. A 10 joule, electrically-pulsed power system produced initial heating in 25μ diameter copper wires. The electrical heating was augmented by optical heating using a pulsed ruby laser. Focused power densities of 10^9 - 10^{10} watts/cm^2 produced breakdown in the expanding copper vapor.

Measurements of the energy deposited in the wire material by both electrical and laser sources were made.

The level of stored electrical energy was adjusted so that a pause in the electrical discharge current occurred at the time of wire vaporization. Measurements of the laser power absorbed in the vapor and the laser power density required to produce breakdown in the vapor were made. These measurements were repeated with varying time delay after vaporization. It was found that the laser power density required to produce breakdown varied from approximately 10^9 watts/cm^2 for a delay of 200 - 300ns to 10^{10} watts/cm^2 for a delay of 3μsec after vaporization.

INTRODUCTION

High energy densities result (ref. 1) when energy stored in a capacitor is deposited in fine wires. The factors which limit the energy absorbed are (1) poor impedance match between the plasma and the electrical source, (2) pause in discharge current, and (3) peripheral arc. With combined inputs from an electrical source and a focused laser beam, it may be possible to eliminate these factors which limit attainment of higher energy density.

The focused light from a high power pulsed laser can produce very high power densities. It is a very efficient source for heating small quantities of material to very high temperatures.

DESCRIPTION OF THE EXPERIMENT

In this experiment two energy sources, a capacitor with stored electrical energy, and a Q-switched ruby laser were used to study the heating of fine copper wires. The electrical discharge first heated and vaporized the copper wire. This was followed, after a time delay that could be varied, by a laser pulse. Studies were made of the interaction between the copper vapor and the focused laser beam.

A schematic diagram of the experiment is shown in Figure 1. Initial heating occurred when a capacitor storing up to 10 J of energy at a potential of 20 kV was discharged through a fine wire with a frequency of 1 MHz. After a preset delay, optical energy from a pulsed ruby laser was deposited in the expanding metal vapor. A study was then made of the interaction of laser light with the copper vapor.

Measurements were made of the incident and transmitted laser power. A spectrograph operated as a monochromator and was used to measure the light emitted from the plasma source due to laser heating.

Other diagnostic measurements, indicated in Figure 1, were made when necessary.

THE EXPLODING CONDUCTOR: TARGET FOR LASER BREAKDOWN STUDIES

In this study the exploding conductor was used as a target for measurements of the interaction of laser light with copper vapor. The results will be useful for devising methods to increase the energy density of exploding wires by laser heating.

At relatively low values of stored electrical energy, the initial discharge current buildup is interrupted by a "pause phenomena" (ref. 1). The pause results in a virtually complete cutoff of current through the wire material and thereby prevents the attainment of extremely high energy densities. The duration of the pause depends upon the diameter and length of the wire, the ambient media, the characteristics of the pulsed power system, and possibly other factors.

Figure 2 shows streak photographs which illustrate some of the phenomena. Photograph A illustrates the current discharge pause. The non-luminous vapor is light while the hot plasma is dark. The duration of the current discharge pause is indicated in the figure. The pause ended with an arc discharge along the center line of the expanding vapor, thus producing a very bright source.

INTERACTION OF LASER BEAM WITH COPPER VAPOR

A research objective was to determine the nature of the interaction of a focused laser beam with expanding copper vapor.

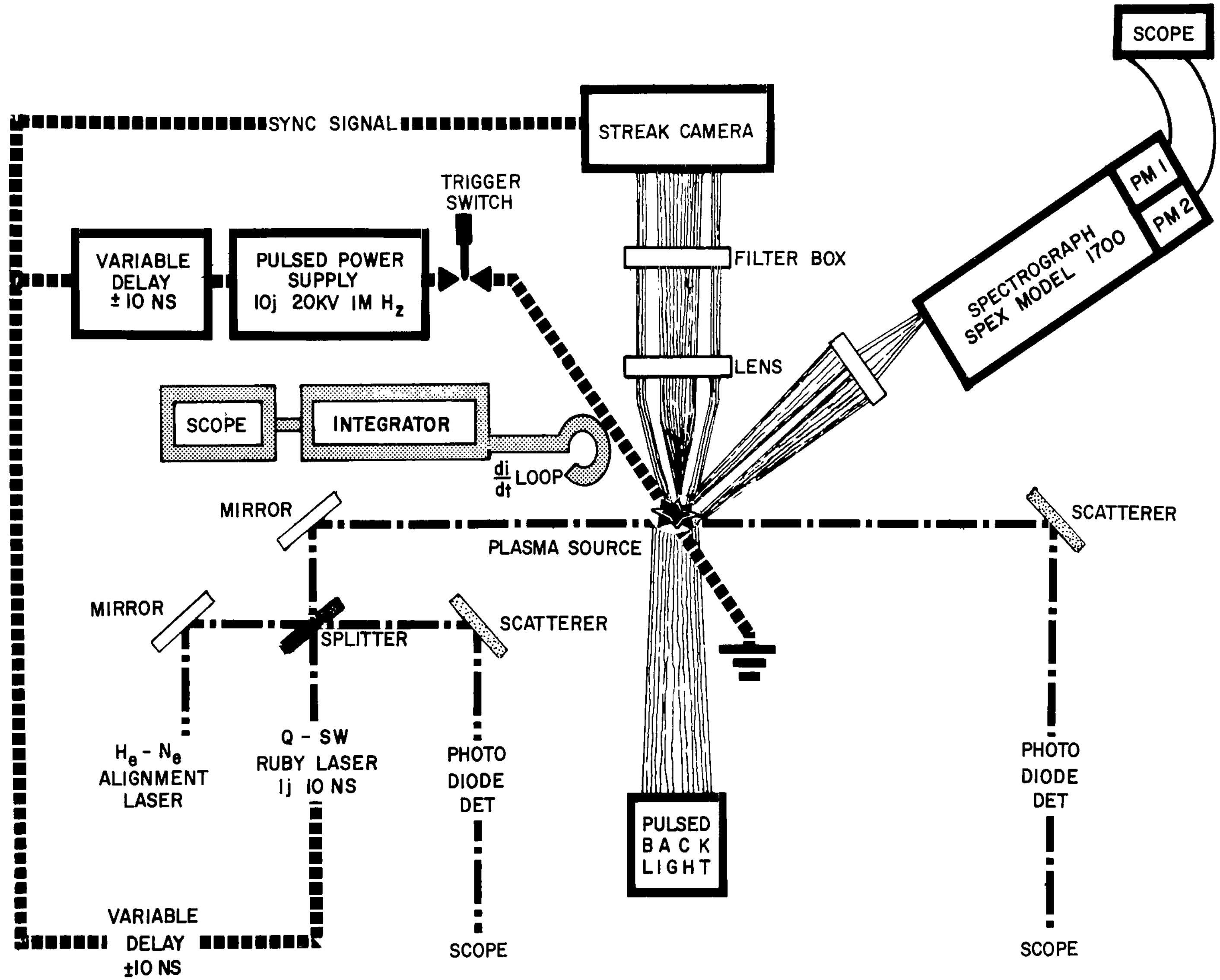
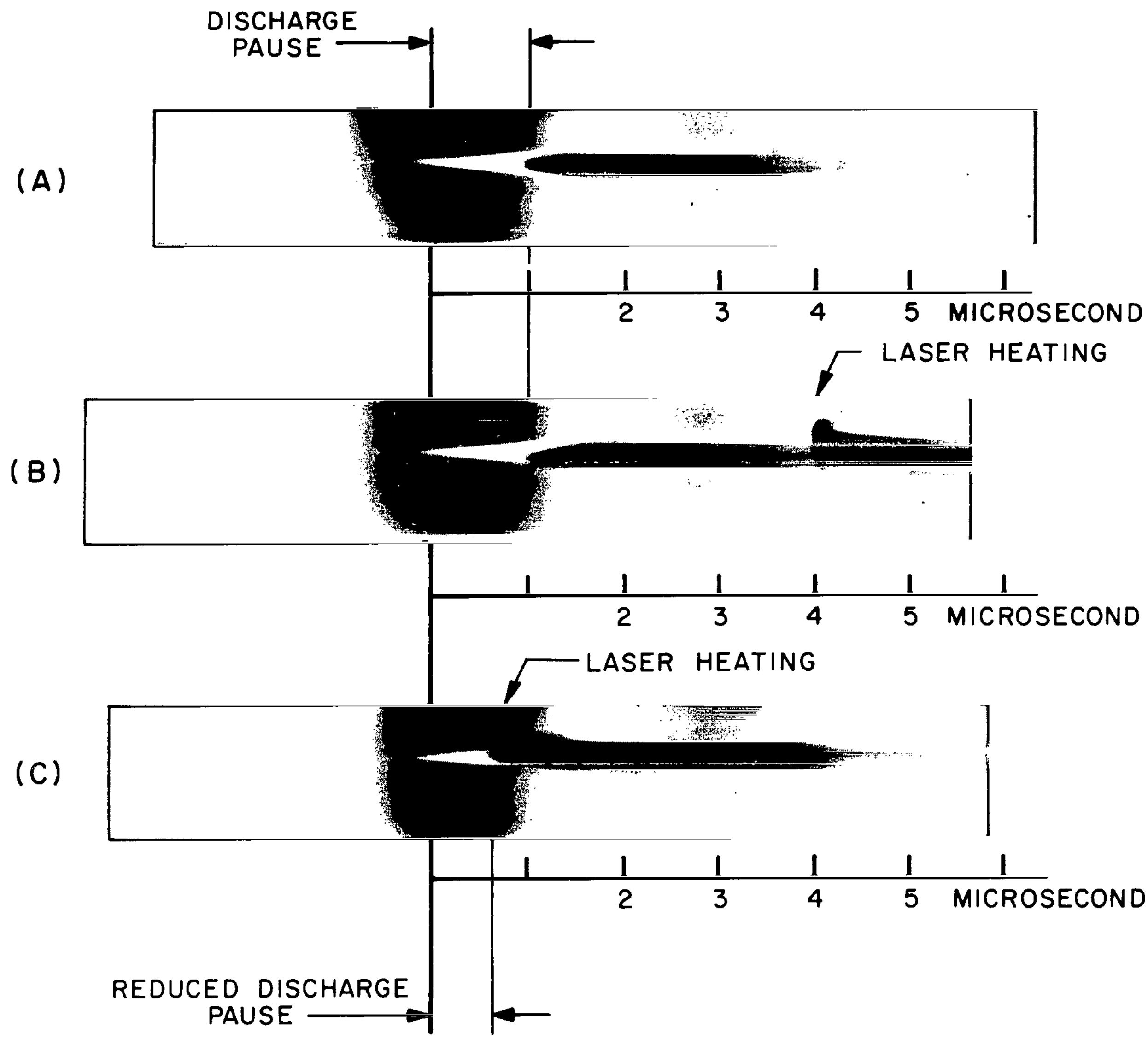


Figure 1.- Schematic diagram of the experiment



(A) ELECTRICAL HEATING

(B) ELECTRICAL AND LASER HEATING (AFTER DISCHARGE PAUSE)

(C) ELECTRICAL AND LASER HEATING (DURING DISCHARGE PAUSE)

Figure 2.- Laser heating of exploding wire

Conditions under which breakdown of the vapor occurred were to be investigated. With vapor breakdown the energy density of an exploding wire plasma source can then be increased by electrical discharge.

Figure 2 (C) is a streak photograph of a laser heating an exploding wire during the discharge pause. The initial breakdown occurred at the center of the vapor and expanded rapidly as is evident in the photograph -- the expansion velocity was greater toward the laser source than away from it.

Figure 2 (B) shows the effects of laser heating an exploding wire, late in time, after the pause was completed. In this case, the heating of the partially ionized wire material was more uniform.

The measurements of laser light absorption in copper vapor during the discharge pause are shown quantitatively in Figure 3.

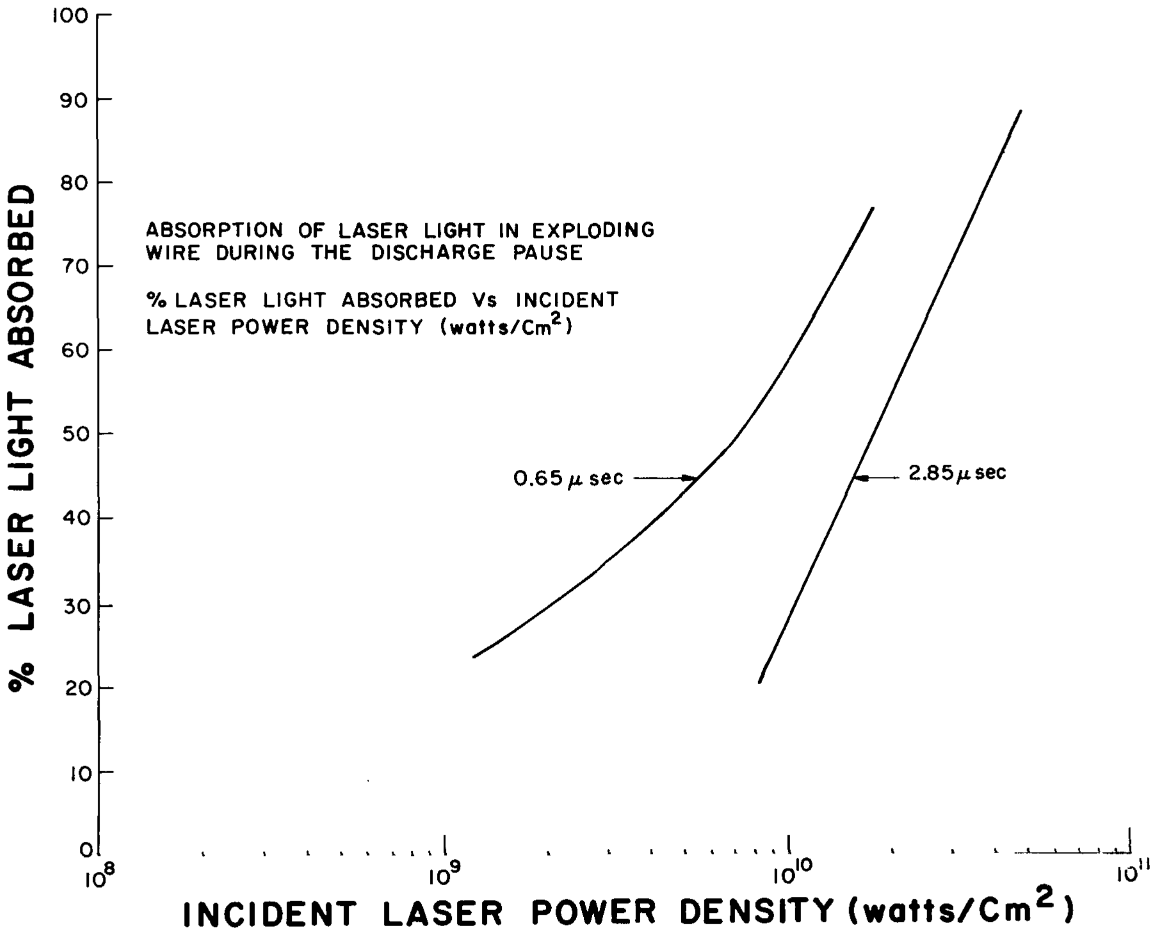


Figure 3.- Absorption of laser light in copper vapor

The percent of laser light absorbed is plotted against the estimated incident laser power density in watts/cm^2. Results are shown for 0.65μsec and 2.85μsec after the beginning of the pause. It is evident that the fraction of laser light absorbed increases rapidly with indident laser power density. The absorption of laser light is also greater for the shorter time delay as indicated in the figure.

From the results of Figure 3, one would expect a substantial increase in the energy density of the plasma for the higher incident laser light intensities. The plasma would then reradiate the energy over a wide spectral range. The results of measuring the relative radiated light from the plasma are shown in Figure 4. The relative light from the plasma, at a wavelength of 5000 Å, is plotted as a function of the incident laser power density. Separate curves are plotted for three different delay times after the beginning of the current pause. The shapes of the curves are typical of those obtained in other laser breakdown experiments (ref. 3). The laser power for which the rate of increase of output light is maximum is used to define breakdown.

In Figure 5, the laser power corresponding to breakdown is plotted as a function of delay time after initiation of the current pause. It is evident that the laser power density required for breakdown increases rapidly with time during the pause. Therefore, if the laser pulse is synchronized to heat the wire vapor within 100 ns or less of the initiation of the pause, a focused laser power of only 10^9 watts/cm^2 will be required to produce an avalanche in the metal vapor. After the avalanche is formed, electrical heating will again produce a higher energy density.

CONCLUSIONS

It has been found that modest focused laser power densities (10^9 W/cm^2) will produce an avalanche in the expanding copper vapor following the onset of the current pause conditions. Such laser heating promotes electrical heating by establishing a conducting filament under higher vapor densities than are attainable by electrical heating alone. Therefore, it is likely that this technique can be used to increase the energy density of electrically exploded wires.

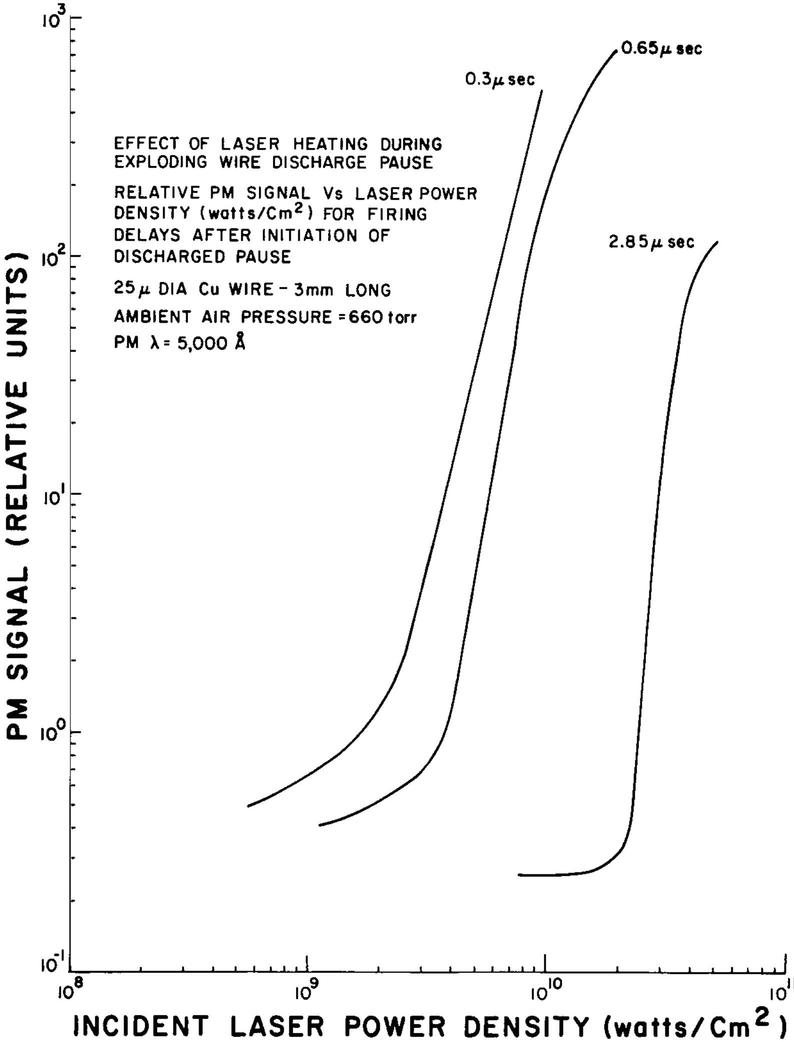


Figure 4.- Change in light emission from copper due to laser heating

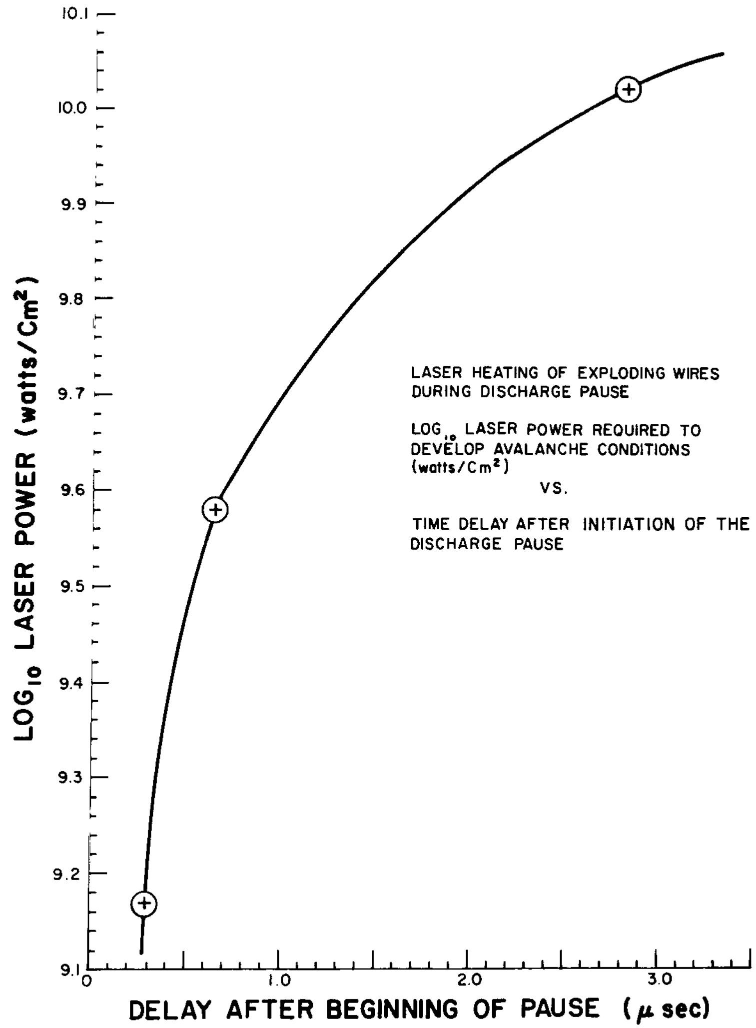


Figure 5.- Laser power density required to break down copper vapor

REFERENCES

1. Bennett, F. D., High-Temperature Exploding Wires, PROGRESS IN HIGH TEMPERATURE PHYSICS AND CHEMISTRY, Vol. 2, Permagon Press, Oxford, 1968.
2. Chase, W. G. and Moore, H. K., EXPLODING WIRES, Plenum Press, Inc., New York, N. Y. 1959.
3. Raizer, Soviet Physics Uspehki, Vol. 8, No. 5, March-April 1966, p. 661.

NASA-Langley, 1970 —— 16 C-123

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546